VIBRATORY MICROGYROSCOPE

BACKGROUND OF THE INVENTION

The present invention relates to a microgyroscope, and more particularly, to a microgyroscope having new type of a vibratory structure and a sensing electrode disposed on the same plane as that of the vibratory structure.

An angular velocity sensor i.e., gyroscope, for detecting angular velocity of an inertial object has been employed as a core part of a navigation apparatus for guided missiles, vessels or airplanes. The gyroscope is currently being employed extending its application fields as a navigation apparatus for automobiles or an apparatus for detecting and correcting hand quiver in a high-magnification video camera. A gyroscope for military or aeronautic purpose is manufactured through precision machining and an assembly process with a multitude of complex parts, provide precision performance. However, due to burdensome manufacturing costs and a large scale structure, such gyroscopes are not appropriate for general industrial purposes or use in home electrical products.

Recently, a small gyroscope with piezoelectric elements attached to a beam of a triangular prism has been developed by the Japanese company Murata, and which is employed as a hand-quiver sensor for small video cameras. Further, to overcome difficulties in manufacturing the gyroscope having piezoelectric elements, another Japanese company, Tokin, has developed another small gyroscope having a cylindric beam structure.

However, since both gyroscopes of the above two types require a precision machining, manufacturing of the same is difficult and expensive. Moreover, since the gyroscopes are made of a multitude of mechanical parts, it is difficult to be developed as part of an integrated circuit.

In the meantime, to improve shortcomings of the above-mentioned gyroscopes, a more economic and accurate gyroscope is under development using a micro machining technology.

The principle of the gyroscope is that when an inertial object which is uniformly vibrating or rotating in a first axis direction receives an input of angular velocity by rotation of a second axis direction perpendicular to the first axis direction, a Coriolis force generated in a third axis direction perpendicular to both first and second axes is detected to thereby detect rotation angular velocity. Here, if the forces applied to an inertial object could be made equal, accuracy of the angular velocity detection would be improved. In particular, it is preferable to make use of equal forces so as to improve linearity and enlarge the bandwidth of a signal.

In FIG. 1, a structure of a comb drive type gyroscope using a tuning fork mode developed by the Charles Stark Draper Laboratory, Inc. is illustrated, which is disclosed in U.S. Pat. No. 5,349,855. The gyroscope shown in FIG. 1 manufactured by the micro machining technology comprises a plane vibratory structure **11**, springs **12** and **13** connected to the vibratory structure **11**, and combs **14** for applying an electrostatic force to the vibratory structure **11**. The vibratory structure **11** is spaced upward from a substrate (not shown) at a predetermined gap and is supported at support portions **15**. As illustrated in the left side of the drawing, the area of the gyroscope can be divided into a surface electrode attached to the substrate, a suspended electrode spaced from the substrate at a predetermined space, and a support region for supporting the suspended electrode.

The micro gyroscope shown in FIG. **1** is operated by applying an electrostatic force using left and right motors with respect to the combs **14** formed at both sides of the vibratory structure **11**. The electrostatic force generates vibration of the tuning fork mode in one direction parallel to the plane of FIG. **1**. The movement of the vibratory structure **11** is detected from the change of the capacitance of the comb **20**. When a voltage capable of inducing vibration satisfying the limit cycle is applied to the left and right motors, the vibratory structure **11** continuously vibrates at a natural frequency.

If the vibratory structure **11** rotates in a direction perpendicular to that of vibration thereof during vibrating movement due to the electrostatic force, the Coriolis force is generated. Such a Coriolis force displaces the vibratory structure **11** in a direction perpendicular to the plane of FIG. **1**. The displacement acts as a torsion force with respect to the vibratory structure **11**. The torsion of the vibratory structure **11** is detected from the change of capacitance by electrodes **22** disposed at two portions under the vibratory structure **11**, from which Coriolis force can be measured. As the vibratory structure **11** is distorted in the direction perpendicular to the plane, an electrostatic force is generated by torque electrodes **23** as an equilibrium method of forces. The torque electrode **23** for making the torsion forces equal is disposed each at two portions under the vibratory structure **11** in a diagonal direction.

The gyroscope according to the conventional technology as illustrated in FIG. **1** has the following problems.

First, it is very difficult to coincide natural frequencies of the vibratory structure **11** with each other in the vibration directions. That is, the planar vibratory structure **11** generally vibrates horizontally as shown in FIG. **2A** or vertically as shown in FIG. **2B**, and each natural frequency of the vibration in both directions should be coincided. To adjust that, the thickness and width of the springs **12** and **13** (in FIG. 1) for supporting the vibratory structure **11** should be defined within a range of predetermined machining errors, which are several to tens of angstroms. Since the processes for machining the thickness and width of the springs **12** and **13** are separated from each other, the coincidence of each natural frequency of the vibration in both directions is very arduous. If the natural frequencies are not adjusted in each manufacturing process, an additional process for adjusting the natural frequencies may be performed. However, that process is very difficult.

To measure the displacement of vibratory structure **11** due to the Coriolis force, the predetermined gap should be maintained between electrodes **22** and **23** attached to the substrate and the vibratory structure **11**. Since the sensitivity of the gyroscope is inversely proportional to the square of the gap distance, it is advantageous to shorten the gap distance in order to increase the sensitivity of the gyroscope. However, since a uniform DC current is applied to the sensor electrodes **22**, the vibratory structure **11** sticks to the surfaces of the sensor electrodes **22** when the gap is considerably narrow. Further, since the change of the capacitance between the surface electrodes **22** and **23** and the vibratory structure **11** is inversely proportional to the square of the gap distance, the linearity of an output with respect to an angular velocity is not good. Additionally, to enhance its sensitivity, the vibratory structure **11** should be designed to be capable of being vibrated greatly in the direction perpendicular to the plane. The greater the displacement of the vibratory structure **11** is, however, the worse the sticking phenomenon of the vibratory structure **11** becomes.

In the gyroscope of FIG. **1**, the torque electrodes **23** are installed at the two diagonal positions under the vibratory